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Model Construction and Application of Deep Learning in Fault Diagnosis of Induction Motor

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Using Helium Mass Spectrometer leak detection method to analyze the PLC-based electrothermal vacuum automatic detection. Using the leakage rate calculation of the helium pass spectrometer leak detection to analyze the detection sensitivity of automatic leak detection system and human-computer interaction system. Qmin=81.6 10 mbar l/s, system average leak detection response time is about 3s. The PLC-based electrothermal vacuum detection system is an advanced detection system at present, it is of high accuracy, fast speed and less interfered by human factors.

1. Introduction

Static pressurizing method, bubbling method, coating method and helium mass spectrometry leak detection method are common air-leakage test methods, since the helium mass spectrometry leak detection method is of high accuracy, fast detection speed, it has been increasingly used in the actual detections. This paper mainly uses this method to conduct analysis of PLC-based electrothermal vacuum automatic detection.

2. Literature review

In the industrial production process, there are quite a number of processes that are difficult to control using traditional control methods, such as nonlinear, complex industrial control objects, difficult to obtain mathematical models or industrial control systems with very rough models. At present, they are still dominated by manual controls. The world's most advanced controller is still human, because humans have a variety of intelligent functions that deal with fuzzy information and intuition. Therefore, for humans, although the precise model of the process is not known, as long as it is empirically judged, reasonable control can be carried out. Several control-purpose complex control systems can also be controlled with ease. Fuzzy control is to achieve superb control capabilities like humans. It can use the human experience directly without relying on the mathematical model of the controlled object to achieve the ideal control objective. Based on the human experience in object operation, fuzzy control uses fuzzy mathematics to infer a set of control laws, which are similar to the following language control rules.
Temperature is one of the important forms of control. In the field of temperature control, the most commonly used is still a simple PID controller. Its share accounts for 80%. Based on the improved PID controller, its share exceeds 90%. Intelligent controllers mainly include fuzzy control, neural network control, and so on. They are commonly used in the theoretical research field, but their actual use is less. The temperature control system is a dynamic system with the characteristics of nonlinearity, pure lag, and time variation. It is not easy to establish an accurate mathematical model. Therefore, research in the field of temperature control has always been an important issue in the field of control science. The application of control algorithms in the field of temperature control is described below.
PID control is the most common and widely used control method in applications. It has the advantages of strong versatility and simple design. However, PID control requires a relatively high control object. It requires an accurate mathematical model of the controlled object, and this mathematical model is generally applicable to linear systems. Therefore, it often performs poorly in temperature control. The advantages of PID control and its strong adaptability have led scholars to further study it and integrate it with other advanced algorithms to meet the requirements of modern control. Wong et al. designed a control parameter tuning method for

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inertial and lagging control objects. This method can improve the control effect to a certain extent, but this method cannot cope with objects with excessive hysteresis (Wong et al., 2014). Sun et al. combined PID control with predictive control and designed a predictive PI controller. The effect of time lag is compensated by the PI prediction part, and the results show that this algorithm has certain advantages for the control of lagging systems (Sun et al., 2016). Lacasa et al. made further adjustments on this basis and improved the controller's robustness (Lacasa et al., 2017).

The essence of fuzzy control is nonlinear control, which belongs to intelligent control. Its control depends on expert experience. Temperature control objects are not easy to establish an accurate mathematical model. For this feature, interference and parameter changes have little effect on the fuzzy control. Therefore, it is particularly suitable for the fuzzy control of such control objects. However, the system stability based on fuzzy control alone is not good, so it needs to be combined with other control methods. Lee and Kang proposed a controller based on fuzzy inference for self-tuning of PID parameters. When the system is in different states, the PID parameters can be self-adjusted through fuzzy inference. Experiments have shown that its control effect and robustness are better than traditional PID control (Lee and Kang, 2015). Gan and Wang designed a fuzzy control and fuzzy PID control combined with a segmented control method for resistance furnace temperature control object characteristics. Simulation experiments show that it has a better performance for uniform rate heating control (Gan and Wang, 2016). Hu et al. proposed an adaptive fuzzy control system. According to the boiler superheated steam temperature system, the mechanism modeling was performed. Combining the coarse and fine adjustment mechanisms of fuzzy control, the controller is self-adjusted to adapt to the time-varying characteristics of the control object. Experiments have shown that this control method has certain advantages for boiler steam temperature control (Hu et al., 2017).

Neural network control is a new technology in the field of automatic control, which combines artificial neural network theory with control theory. It is a new branch of intelligent control. Multi-layer network structure, good self-organizing self-learning ability, good fault tolerance and good search ability make it a new way to solve nonlinear and uncertain control systems. Li et al. studied the feed-forward neural network controller. For greenhouse temperature control, the controller designed by Elman neural network principle was used to control it. Simulation results show that this method outperforms traditional control effects (Li et al., 2015). Some scholars combine genetic algorithm with neural network control and PID control, and propose an adaptive PID controller that uses BP neural network optimized by genetic algorithm to make PID online self-adjustment. Simulation results show that this method can effectively control complex control objects (Guo et al., 2016).

In summary, it can be seen that the formulation of the temperature control strategy is the main factor affecting the accuracy of the heat loss value test and the test efficiency. However, the research algorithms for temperature testing in the above studies lack application-type temperature control algorithms. Therefore, the temperature control algorithm was studied. First, a mathematical model of the control system was established through experimental modeling. Based on this, taking into account the unidirectionality, hysteresis, and nonlinearity and time-variation characteristics of the actual temperature control object, the commonly used PID control in practical applications is compared with the fuzzy control to design a fuzzy adaptive PID. Then, it is optimized by genetic algorithm. Finally, through simulation experiments and field tests, this control algorithm is validated for the feasibility and effectiveness of the collector heat loss test. In addition, through the analysis of field experimental data, it can effectively improve the temperature test accuracy and test efficiency.

3. Experimental principle

Essentially, the helium mass spectrometry leak detection is to use the mass spectrometry leak detector to determine the leakage rate by detecting how much helium has past the leak. The principle of mass spectrometer leak detector is shown in Figure 1, when the gas molecules enter the mass spectrometer leak detector, under the electric field and magnetic field, the molecules deflect and most of them hit the orifice plate, only the matching ions can pass through the small hole in the middle of the orifice plate and enter the right half of the magnetic field, and then collected by the ion pole. By measuring the ion flow we can know how much gas leaks through the hole, and then calculate the leakage rate.

4. Experimental method

Helium mass spectrometry leak detection methods usually include injection method, sniffing probe method, back-pressurizing method, and vacuum chamber method. For the vacuum chamber leak detection, there are two methods: one is inner vacuum method, another is outer vacuum method. The system in this paper uses the outer vacuum method, its leak detection principle is shown in Figure 1. Its specific leak detection method is: place the workpiece in the vacuum chamber, fill in the helium gas with certain air pressure, the helium gas enters the vacuum chamber through the leak on the workpiece, and detected by the helium mass spectrometer leak detector which is connected to the vacuum chamber, then we can get the leakage rate of the workpiece.

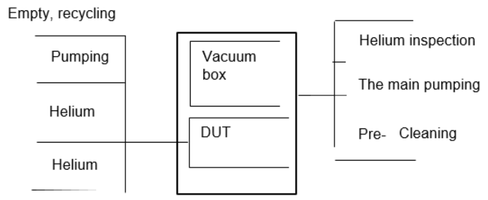

Figure 1 : Outer vacuum method leak detection principle

5. Experiment procedure

5.1 Leakage rate calculation of helium mass spectrometry leak detection

According to the definition of leakage rate, we can get the formula of leakage rate:
$Q=P*V/T$
Where: P—pressure; V—volume of test piece; T—time;
According to national regulations, the annual allowed refrigerant leakage for the household and car air-conditioners is 2 g, the leakage rate is calculated when the refrigerant R22 is under 1 atm (the molar mass of refrigerant R22 is 86.5). The Boyle-Charlie's law is shown in following formula:
$PV=nRT$
Where P is the gas pressure (mbar), V is the gas volume, n is the gas mole number, R is the gas coefficient (R = 82.9388) and T is the absolute temperature (K).
We can calculate that, under the standard state, the volume of 2g R22 is 0.518 liters. So, under 1 atm, the annual leakage rate for 2g R22 is Q = 1013 × 0.518 ÷ 31536000 = 51.66 10 mbar l/s.
Under different pressure, the same leak would have different leakage rate. According to the relationship between pressure difference and gas amplification coefficient shown in Table 1, we can calculate corresponding leakage rate for different pressures. If the system conducts leak detection at a helium pressure of 1 bar, the leakage rate that needs to be detected is 4.4 × 10-7 mbar l/s. When the system conducts the leak detection under 8 bar helium pressure, the leakage rate that needs to be detected is 4.4 × 10- 7 × 26 = 1.14 × 10-6 mbar l/s. (See Table 1)

Table 1: Pressure and gas amplification coefficient

Refrigerant pressure difference ΔP/bar	Gas magnification
1	1
5	10
8	26
10	32
15	70
30	220

5.2 Design for the vacuum helium mass spectrometry automatic leak detection system

The vacuum helium mass spectrometry automatic leak detection system can be divided into vacuum system, leak detection system, electrical control system, and human-computer interaction system. The vacuum system is responsible for obtaining and maintaining the working vacuum degree required for the helium mass spectrometry leak detector, mainly including vacuum pump, vacuum gauge, vacuum chamber and other vacuum components. In the design of the vacuum system, two main problems are considered: one is to consider the pump selection, and determine whether the pumping speed meets the system design requirements, and whether the required degree of vacuum can be achieved within given time; another is the design of vacuum chamber, including the vacuum chamber shell design, wall thickness design, intensity check, etc.
The pumping speed of the pre-pumping pump is selected based on the volume of the vacuum chamber, the allowable pre-pumping time and the pre-evacuation rate to be achieved. The nominal pumping speed of the pre-pumping pump is calculated as shown in the following formula:

$$Sp = 2.3K\, V/T * \lg Pa/Pb$$

Where T is the pumping time, SP is the nominal pumping speed of the pre-pumping pump, V is the volume of the vacuum tank, Pa is the initial pressure in the vacuum tank, Pb is the vacuum degree after the pumping time T, and K is the correction coefficient.
For the pumping speed of the main pump, it is determined by the system leakage, outgassing quantity and the required working pressure. The nominal pumping speed of the main pump is calculated as shown in the following formula:

$$S = \frac{Q1+Q2+Q3}{P}$$

Where, S is the effective pumping speed of the main pump, P is the working pressure required for the leak detection process, Q1 is the gas leakage during the leak detection process, Q2 is the outgassing quantity of the vacuum chamber, Q3 is the leakage of vacuum tank. In the actual selection process, we increase the theoretical effective pumping speed by 20% to select the effective pumping speed of the pump.
The vacuum chamber uses a box-shaped shell, and sets a chamber door, the door is rectangular and flat covered, sealed by the seal ring. The wall thickness of the vacuum chamber is calculated according to the rectangular plate, and we can calculate the theoretical wall thickness by the following formula:

$$S = \frac{0.224B}{\sqrt{[a]}}$$

Where, S is the theoretical wall thickness, B is the length of the narrow side of the rectangular plate, [a] is allowable stress when bending. The applicable conditions are: the periphery of the plate is fixed, subject to external pressure 0.1MPa, hydraulic test pressure P is 0.2MPa. The actual value of wall thickness is based on the theoretical wall thickness, an additional amount is added to ensure that the structure of the vacuum chamber is stable and meets the strength requirements.

5.3 Leak detection system

Leak detection system achieves the leak detection work for the products, it can be divided into two parts: nitrogen leak detection and vacuum helium leak detection, including the pipeline valve system, gas distribution system, helium mass spectrometer leak detector, etc. The leak detection system mainly considers the design of the pipeline, including the conductance of the pipeline, the diameter of the pipeline and the arrangement of the pipeline, so as to ensure that the leak detection system can rapidly achieve the set vacuum degree and minimize the residual leakage gas.
In order to increase the effective pumping speed and the conductance of the pipeline, the pipeline should be as coarse and short as possible, and the pipe bends and turns should be avoided. Due to the limited space of the system, a combination of curved pipes and straight pipes in series or parallel is actually adopted. For a single long tube, the conductance calculation is shown in the following formula:

C=π/128*D4/ηL*P

Where C is the conductance, η is the viscosity coefficient, L is the length of the pipe, D is the diameter of the vacuum pipe, P is the average pressure in the pipe. For the calculation of the conductance of the elbow section, the conductance of an equivalent straight pipe can be used instead, its equivalent length is shown in the following formula:

$$L_{equivalent} = L_{axiallength} + \frac{4}{3}D$$

In the system, the total conductance of the pipelines in series is the sum of reciprocal of conductance of the pipeline in each section; the total conductance of the pipeline in parallel is the sum of conductance of the pipeline in each section. The system's vacuum line is a long tube line. For a long vacuum tube line, the gas flow state can be regarded as viscous flow, therefore, according to the viscous flow discriminant and the pipeline average pressure when the pipeline is under the vacuum degree during the leak detection, we can estimate the diameter of the pipeline. The viscous flow discriminant is as follows:
DP≥0.665
The gas distribution system is divided into two parts, nitrogen part and helium part. All of the gas lines and the air exhaust lines after the detection are integrated on a valve terminal for convenient and reliable operation.

For the helium mass spectrometer leak detector, we select INFICON LDS2010, which can meet the requirements of a variety of communication functions, with a variety of detection modes, the conservative data of the minimum detectable leakage rate is less than 1 * 10-9 mbar l/s, in full compliance with product leak detection requirements.

5.4 Human-computer interaction system design

As the human-computer dialogue function of the PLC is weak, we use the touch screen as the operation terminal of the system. Through the communication between the touch screen and the PLC, the current running status of the system can be displayed on the touch screen, the working status of each component and station can be monitored, such as the pressure, degree of vacuum and the like. According to leak detection process and system requirements, on the touch screen, we set up five interfaces: automatic running, manual detection, parameter settings, system settings and user login. For each interface, corresponding privileges are set in each interface, with different privileges you can open different interfaces, thus making the management levels of the entire system clearer and more humane.

5.5 Experimental process of vacuum helium mass spectrometry leak detection

5.5.1 Clamping

The workpiece is connected to the vacuum system (see Figure 2), the operator only needs to put the workpiece into the clamp, then the system will automatically clamp the workpiece.

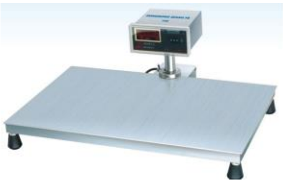

Figure 2: Automatic vacuum testing machine

5.5.2 Major leak detection

After the test piece is installed, the vacuum chamber is closed, dry high-pressure nitrogen gas is filled into the test piece for major leak detection, and the pressure-dropping method is adopted to determine whether there is a major leak. If the workpiece under test has a major leak, the system will sound an alarm and end the test; if there is no major leak, then the system enters the helium mass spectrometry leak detection stage.

5.5.3 Pre-pumping

The helium mass spectrometer leak detector (see Figure 3) works under high vacuum conditions, so before conducting the helium mass spectrometry leak detection, the vacuum chamber must be pre-pumped by the pre-pumping pump to quickly evacuate the vacuum chamber until the pressure is below 1 mbar, at the same time, the nitrogen in the test piece is evacuated to make preparation for the helium mass spectrometry leak detection in the next step.

Figure 3: Helium mass spectrometer leak detector

5.5.4 Helium mass spectrometry leak detection

When the vacuum chamber reaches the set vacuum degree, the leak detection valve opens, the pipeline between the vacuum chamber and the helium detector is conducting (see Figure 4), the leak detector automatically clears the background, fills helium gas into the test piece until reaches the pressure of leak detection, the detector starts leak detection automatically and reads the leakage rate of the product.

Figure 4: Helium mass spectrometer leak detector

5.5.5 Uninstall workpiece

After the leakage rate data is read, determine whether the product is qualified or not. The purge valve fills the vacuum chamber with nitrogen, and blows away the helium gas that might enter the vacuum chamber to reduce the helium background, then uninstall the workpiece and finish the leak detection.

6. Experimental results

PLC-based electrothermal vacuum detection system has two important performance indicators: leak detection sensitivity and detection response time. Through the actual test, the system detection sensitivity Qmin = 81.6 10 mbar l/s, which meets the design requirements. The leak detection response time refers to the required time from the time when the leak gas enters the detection system from the leak on the test workpiece, until the detector reaches and stays at the maximum leakage rate. Through the test, the system average leak detection response time is about 3s.

7. Conclusion

The PLC-based electrothermal vacuum detection system is an advanced detection system with high accuracy, fast speed and other significant advantages. In the test, we only need to replace the workpiece clamp in the vacuum chamber, so it’s quite convenient. And the PLC-based electrothermal vacuum detection system is less disturbed by human factors, which ensures the accuracy for the detection results. From actual situations, we can see that the PLC-based electrothermal vacuum detection system can better protect the circuit motor, and is widely used in actual operations, thus it has great developing potential in the future.

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